# *8. Search for Habitable Planets*

We know of one **habitable** planet in the Universe, habitable meaning suitable for supporting life such as that we are familiar with. That one habitable planet is our own: Earth. For centuries, some people have speculated that there may be many many such planets in other planet-star systems. Until the latter part of the 20th century, there was no evidence that planets of any sort around other stars even existed, much less habitable planets like Earth. That's not surprising. It's nearly impossible to see exoplanets because they are very distant, very faint and lost in the overwhelming glare of the stars they orbits. As of July 2007, only four exoplanets were observed with direct imaging methods—planets that were very large and orbiting very faint stars with very large orbit radii. But although we cannot easily observe exoplanets directly, we have detected lots of them by certain effects they have on the stars they orbit. Here are the main methods that have been thought of:

The first detection of extrasolar planets was made by Alexander Wolszczan in 1994 by measuring the periodic change in arrival time of radio pulses from a pulsar—an incredibly dense neutron star remains of a supernova that normally emits very regular pulses of radio waves.

Most exoplanet discoveries have been the result of looking for movement of the "parent" star. In Kepler's Laws, the Sun is fixed at a point in space and the planet revolves around it. But why should the Sun be thus privileged? Kepler had rather mystical ideas about the Sun that justified its special place. However Newton, in connection with his 3rd Law, showed that the Sun does not occupy a privileged position. As a planet orbits its star, its gravity affects the star so that the two bodies actually orbit each other. Of course the larger body dominates and the smaller body moves a lot more. But the small movement of the star as the orbiting planet tugs on, in theory can be detected in two ways: (1) if the star alternately moves towards us and away from us, its spectrum should shift slight back an forth, alternately towards the blue end then towards the red end—a **spectroscopic shift**. (2) We should be able to see the position of the star shift as well. Accurate measurement of position is known as **astrometry**. Spectroscopes have been used to detect star spectrum shifts caused by orbiting giant planets. From ground-based observatories, spectroscopists can measure shifts due to velocity changes as small as 3 m/sec. This corresponds to a planet at least 33 times the mass of Earth orbiting a Sun-like star. No exoplanet detections have been confirmed using astrometry, but there have been many exoplanet discoveries with the spectroscopic method.

Planets orbiting other stars are called **exoplanets***, or* **extrasolar planets***. Planets in any way similar to Earth are called* **terrestrial planets***.*

8.1 What factors make a planet habitable?
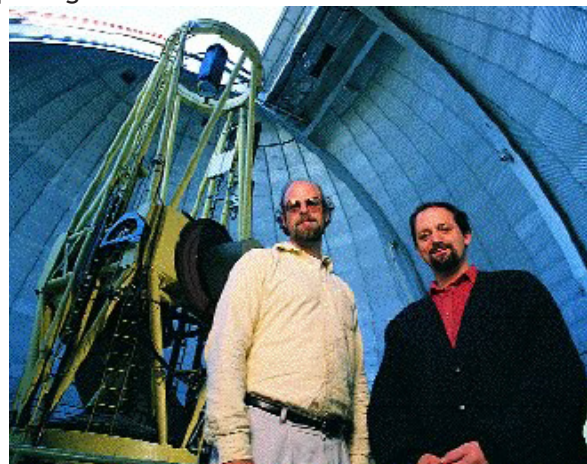
Geoffrey Marcy (right) and Paul Butler at Lick Observatory, where they made their first exoplanet discovery in 1987: 70 Virginis b in the constellation Virgo and 47 Ursae Majoris b in the Big Dipper. (photo: Mickey Pfleger)

For up-to-date accounting of all exoplanet discoveries, see The Extrasolar Planets Encyclopaedia at http://exoplanet.eu/

The other practical way to discover exoplanets is to watch the periodic dimming of the star caused by a planet passing in front of the star—an event known as a **transit**. Measuring brightness is known as **photometry**. This method in theory, with four years of observing, could detect planets about half the mass of Earth in a 1 AU radius orbit about a sun-like star or a Mars mass planet in a Mercury-like orbits. Planets with orbital periods greater than two years are not readily detectable, since their chance of being properly aligned along the line of sight to the star is very small. Photometry is the only practical method for finding Earth-size planets in the habitable zone.

Exoplanet Transits

Plot and analyze a light curve for a planet transit. Then, from transit data, find out critical properties of a planet that could make the planet habitable or not.

This is a rather idealized light curve—most are quite a bit more rough or difficult to discern the brightness drop.

Orbital Phase (2005 Jun 6)

Materials

- HOU IP software and computer
- 19 Images of star SAO_107623 *

These are 19 observations of the a star named HD209458 during a transit. This was the very first star for which planet transits were observed. The planet had already been discovered by the spectroscopic method. The planet is known as HD209458b. Planets around a star are designated by a letter of the alphabet, with the star taking the letter "a" and each orbiting body taking a letter in the order of their discovery. Thus, HD209458b is the first planet discovered around star HD209458. Each image is really 20 or so images "stacked" on one another so that "noise" in the resulting image is kept to a minimum.

First let's have another look at graph E of the light curves near the end of chapter 6.

8.2. What would determine how much dimming occurs during a transit of a planet in front of a star?

8.3. What would affect how long the transit lasts?

8.4. What would determine how often a transit occurs?

8.5. What properties of a planet could we tell from observations of transits?
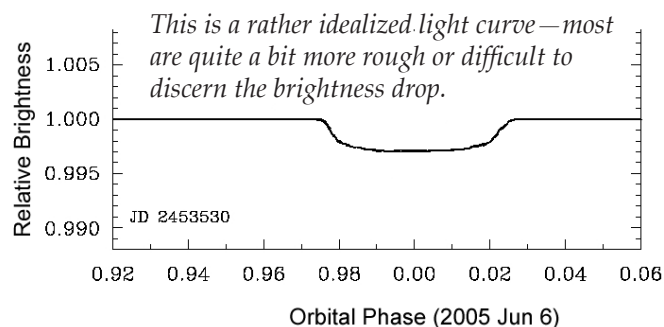
Check the "Staying Up To Date" web pages for A Changing Cosmos *chapter 8* http://lhs.berkeley.edu/gss/uptodate/10acc *for possible new sets of images for* Exoplanet Transits.

I: Plot a Transit Light Curve

In order for a planet transit to be observed:

- The planet's orbital plane must be in line with our view of the star (as with eclipsing binary stars).

- The planet must be large enough for us to detect a drop in brightness. Earth based observations can detect a drop of 1% from a transit of a Jupiter sized planet.

With each of the nineteen images of HD209458, use the following procedure (like the *Finding Supernova* investigation–Chapter 6)

A. Find the time of each image from the Image Header Info. Find the difference, in minutes, between the observation time and the time of the first image (i.e. 10/20/2001, 3:06 UT).

B. Identify the correct star on the image. Use your judgment (or a finder map if available), For the image set of star SAO_107623, the star that is the brightest is HD209458 so take some Counts measurements using the Aperture tool.

C. Find reference star(s). Use the bright star about 45° to the upper right of HD209458 as a reference star.

8.6. Using Aperture, measure and record the Counts of HD209458 and the reference star. Then divide the Counts for HD209458 by the Counts of the reference star to get the Count Ratio for each image. Make a light curve for HD209458 by plotting the Count Ratio versus time (in min). Before graphing, look at the range of Count Ratios and optimize the range of y-axis values (maximum value just above the highest Count Ratio, and the minimum value just below the lowest Count Ratio on the axis).

II: Examine the Light Curve

DURATION

8.7 If you do not have data for a full transit, is there any way you could still determine the transit duration?

8.8 What was the duration of the transit you plotted in Part I?

8.9 Would the duration be the same for all transits of a given star-planet combination?

TRANSIT DEPTH

Transit Depth is the dip in the light curve. This is the drop in brightness of the star as a planet passes in front of it.

8.10 What is the Transit Depth (TD)—the maximum dip in brightness— of the transit you plotted in Part I, expressed as the ratio between the brightness before the transit and the brightness at the deepest point in the curve?

TD = fraction decrease in brightness of the star due to the transit

$\quad\quad = (B_1 - B_2)/B_1$ or $(C_1 - C_2)/C_1$ [B = brightness; C = Counts]

8.11 What makes it difficult to find the Transit Depth for this planet?

III: Find the Planet's Size

The transit depth (TD) related to the size of the planet in a very simple way: the area of light blocked when the planet transits is exactly the area of the apparent disk of the planet. So, the ratio of area of planet disk to star disk should directly determine the drop in brightness.

TD = (area planet)/(area star)

Since area = πr^2 ,

TD $= (\pi r_{planet}^2)/(\pi r_{star}^2)$

TD $= (r_{planet}/r_{star})^2$

8.12. What is the radius of planet HD209458b? First find the radius of star HD209458a (from Internet or clues from teacher or colleagues) and then use the transit depth equations in both II and III to find the radius of the planet]

PERIOD

8.13. What does Kepler's Third Law tell us about how the period of a planet is related to its distance from a star?

One light curve cannot show the period of the planet. The star must be observed for many days, weeks or months in order to establish that the transits occur in a regular period.

8.14 What is the period of planet HD209458b? (Use library or Internet search.)

IV: Find the Distance of the Planet from its Star

8.15 Using Kepler's Third Law, what is the orbit radius of planet HD209458b in Astronomical Units?

Distance Matters

The distance of the planet from its star gives us crucial information about its possible habitability. Again, it's like the Goldilocks story, but even closer analogy, since the "soup" will be either too hot or too cold for life. More precisely, the temperature must be in the range to allow for liquid water, which is an essential ingredient for nearly all life forms that we know of. If the planet is too close to its star, all water vaporizes, and if the planet is too far from its star, water is all frozen.

To find out about the NASA mission to find Earth-size exoplanets, see the *Kepler* mission website - http://kepler.nasa.gov

b-v magnitude	Surface Temperature (Kelvin
-0.31	34,000
-0.24	23,000
-0.20	18,500
-0.12	13,000
0.00	9,500
0.15	8,500
0.29	7,300
0.42	6,600
0.58	5,900
0.69	5,600
0.85	5,100
1.16	4,200
1.42	3,700
1.61	3,000

V: Conclusion—Is the Planet Habitable?

8.16. What factors besides distance from star might impact the temperature of a planet?

8.17 Is planet HD209458b habitable? Justify your answer with results from parts I through IV of this investigation.

More advanced exoplanet investigation

Visit the TransitSearch website - *http://www. transitsearch.org* - to find and download data on exoplanets with observed transits. Find the time between consecutive transit observations to find period. Find the transit depth. If possible, get information about the parent star to determine the size of the planet and its orbit radius.

Visit the Sloan Digital Sky Survey (SDSS) web page on *Calculating the radius of a star* - *http://cas.sdss.org/dr6/en/proj/advanced/hr/radius1.asp*. See the meaning and derivation of a formula that can be used to compute a star's radius in relation to our Sun's radius:

$$R/R_s = (T_s/T)^2 (2.51)^{(m_s-M)/2}$$

Where R = star radius

R_s = Sun's radius

T = Temperature of the star

T_s = Temperature of the Sun

M = absolute magnitude of the star

m_s = absolute magnitude of the Sun = 4.83

Relationship of b-v magnitude and temperature is in chart at left.

Absolute magnitude is

M = m - 5 log d + 5

Where d = distance to the star in parsecs.

Use Hipparchos skyplot, to find parallax, distance to star, and compute absolute magnitude.   *http://www.rssd.esa.int/SA-general/Projects/Hipparcos/skyplot.html*

Finally, visit the AAVSO website (*http://www.aavso. org*) and look for any exoplanet "campaigns" that are there (e.g on http://www.aavso.org/news/campaigns.shtml)

Also, try getting names of stars known to have transiting exoplanets from *http://exoplanet.eu/catalog-transit.php* (52 as of July 2008) and then do a search on the AAVSO website for any light curves they have for any of those stars.

Find late breaking news and information about the Search for Habitable Planets *at the* Staying Up To Date *pages for* A Changing Cosmos*:*
http://lhs.berkeley.edu/gss/uptodate/10acc